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Review Article

Recent advancements and the potential for growing *Rosmarinus officinalis* L., a new fragrant, medicinal, and industrial crop: A review

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Abstract: *R. officinalis* is an ancient plant with medicinal properties that is used to cure a variety of ailments. Utilizing plant-based products such as phytocompounds, extracts, essential oils, and tinctures, has shown in research how successful it is in phytotherapy. Extracts from rosemary are used in a variety of natural products, medications, and food preservation techniques. Carnosic acid, rosmarinic acid, ursolic acid, oleanolic acid, flavonoids, and phenolic acids are among the 140 compounds found in the essential oil. As an antibacterial and bactericidal agent, rosemary is often utilized as a skin conditioner and scent in cosmetic products. Every year, 200–300 metric tons of oil are produced worldwide. In the right amounts, it is frequently utilized as a skin conditioner and scent in cosmetic products. It prevents makeup from deteriorating and has great potential for topical application. The proteins, fiber, vitamins, and minerals contained in rosemary are recognized as having disease-preventive properties. The main bioactive components and the mechanisms of action require more investigation. The present study aims to provide a consolidated knowledge base that can help researchers, farmers, and industry stakeholders fully exploit rosemary as a fragrant, medicinal, and industrial crop by combining multidisciplinary data using a systematic review strategy.

Keywords: Antioxidants, Anti-inflammatory activity, Aromatherapy, Essential oils, Rosmarinic acid, Sustainable agriculture

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1. Introduction

Rosmarinus officinalis L., commonly known as rosemary, is a perennial aromatic shrub native to the Mediterranean region and widely cultivated across the globe for its culinary, medicinal, and industrial applications. It is a fragrant and therapeutic herb from the Lamiaceae family. Rosemary is thought to be one of the most significant sources of volatile and non-volatile bioactive compounds. It is valued for its essential oils, phenolic compounds, and other bioactive metabolites, which possess antioxidant, antimicrobial, anti-inflammatory, and neuroprotective properties. Over the last two decades, rosemary has attracted significant scientific interest due to its potential in the food, pharmaceutical, cosmetic, and agro-industrial sectors, making it a high-value crop for diversification and sustainable agriculture.

The essential oils and phenolic chemicals found in rosemary's leaves and blossoms are responsible for its pleasing scent. It grows up to 1.5 meters in height and is an evergreen shrub [1]. For commercial purposes, the herb can be harvested 3-4 times a year [2,3]. The dried herb and oil extracted from the whole herbs of the plant are employed in the food, flavor, and fragrance sectors. Rosemary oil is also utilized in aromatherapy [2-5].

The herb is hydro distilled to produce rosemary oil [3, 6]. Between 200 and 300 metric tons of oil are produced worldwide every year. Rosemary is promising for topical application and protects cosmetics from deterioration. Proteins, fiber, vitamins, and minerals found in rosemary are recognized to provide anti-disease effects, generally "anti-disease" refers to actions, therapies, or materials that stop or prevent diseases [5,6]. By integrating multidisciplinary data through a systematic review approach, this study aims to provide a consolidated knowledge base that can guide researchers, farmers, and industry stakeholders in harnessing the full potential of *Rosmarinus officinalis* as a fragrant, medicinal, and industrial crop.

To achieve this, a systematic literature search was conducted in the major scientific databases including Web of Science, Scopus, PubMed, ScienceDirect, and Google Scholar. To ensure the inclusion of both fundamental works and contemporary innovations, the literature selection period covered the years prior to 2000 to 2025. The search keywords included combinations of terms such as "*Rosmarinus officinalis*", "*rosemary cultivation*", "*rosemary essential oil*", "*rosemary pharmacology*", and "*industrial applications of rosemary*". Inclusion criteria encompassed peer-reviewed journal articles, review articles, technical reports, and book chapters that provided data on cultivation techniques, phytochemical profiling, biological activities, and industrial relevance. Studies were excluded if they were non-English publications without accessible translations, lacked experimental or analytical details, or were purely anecdotal.

2. Origin of rosemary

Rosemary has been grown all over the world for a long time, and because of its lovely scent, rosemary has been grown as a garden plant in recent years. The geographical distribution area of the plant particular is the Mediterranean region and areas with a Mediterranean climate. Rosemary is native to the Mediterranean region and grows wild in Algeria, France, Italy, Portugal, and Spain, and is cultivated in the USA, India, and Spain [8-9].

The Niligiris in India was the first to use rosemary a

Figure 1. a. Rosemary plant, b-d. Morphological variations in the plant twigs and leaves of rosemary

few decades ago. The Nilgiris district is one of 38 districts in the southern Indian state of Tamil Nadu. The word "Nilgiri" describes a collection of mountains scattered along the borders of Tamil Nadu, Kerala, and Karnataka. The Nilgiri Hills are part of a larger mountain range known as the Western Ghats. The Cinchona Department cultivated rosemary to produce a small amount of oil. At that time, there were no initiatives to begin commercial cultivation of the plant or oil production. In the late 1980s, trials on the cultivation methods of the plant were conducted at the research center of CSIR-CIMAP (Council of Scientific and Industrial Research-Central Institute of Medicinal and Aromatic Plants) in Bangalore [8-9].

3. Botanical description and taxonomy

As a xeromorphic plant, rosemary thrives natively in sand, stony, and cliffy locations near the ocean throughout Asia, Europe, and Africa [6, 8, 10-11] (Figure 1). Table 1 provides additional details on the botanical description.

Table 1. The taxonomic classes and botanical descriptions of *Rosmarinus officinalis* L.

Kingdom	Plantae	Botanical descriptions
Sub-kingdom	Tracheobionta	Rosemary is a perennial herb that belongs to the "Lamiaceae" family. More than 20 different types, varieties, or cultivars of rosemary can be distinguished according to morphological descriptors (such as calyx, corolla, dimensions of leaf, inflorescence, and the presence of glandular trichomes). It is a dense, branched, evergreen shrub with bluish-white flowers, reaching a height of about 1 meter. It is characterized by having leaves that are 1–4 cm long and 2–4 mm broad, sessile, leathery, linear to linear-lanceolate, with recurved edges, dark green upper surface and grainy and soft lower surface, prominent mid-vein, and a very characteristic odor. Leaves and flowers have a strong, fragrant characteristic odour due to the volatile oil accumulated in typical peltate and capitate glandular trichomes. Many different varieties and cultivars are grown, each varying in flower colour (blue/pink/white), plant habit (erect/spreading), leaf colour (olive/blue/green), size of leaves, etc.
Super division	Spermatophyta	
Division	Magnoliophyta	
Class	Magnoliopsida	
Subclass	Asteridae	
Order	Lamiales	
Family	Lamiaceae	
Genus	RosmarinusL.	
Species	officinalis	
Botanical nomenclature	Rosmarinus officinalis L.	

4. Inclusion and exclusion criteria for the literature

A summary of the databases, timeframe, and inclusion/exclusion standards applied during the literature selection process. A methodical process was used to choose pertinent scientific material in order to guarantee a thorough and current review of rosemary. The literature search was conducted using PubMed, Scopus, Web of Science, ScienceDirect, and Google Scholar as the main databases. Key terms including "*Rosmarinus officinalis*", "rosemary", "phytochemistry", "medicinal properties", "essential oils", "antioxidant activity", "agronomic practices" and "pharmacological effects" were used in the search. Priority was given to articles in peer-reviewed journal, review articles, and reputable book chapters and the timeframe 2000–2024 was taken into consideration for inclusion.

The inclusion criteria focused on studies that provide new information or noteworthy reviews on the phytochemical composition of rosemary, its medicinal uses, its agronomic traits, and its most recent developments in breeding and production. English-language publications and research containing quantitative or qualitative information pertinent to the therapeutic, aromatic, or agricultural uses of the plant were selected. Studies that focused on unrelated species or aspects (e.g., culinary use without medical value), lacked scientific rigor, were anecdotal, or were not peer-reviewed were excluded. A strong and targeted synthesis of current knowledge and research trends was made possible by this systematic technique, which ensured that the evaluated literature included the most pertinent and scientifically proven material on rosemary.

5. Medicinal uses and medicinal properties of Rosemary

Rosemary is used as a flavoring in cooking, food preservation, and in cosmetics. The proteins, fiber, vitamins, and minerals contained in rosemary are recognized as having anti-disease effects. Nowadays, a lot of research is being conducted on rosemary as a food additive. This fragrant herb serves as an antioxidant and antibacterial and can be added directly into food or mixed into food packaging [2-3, 12-19]. The market for herbal products is rising globally, and many of them have been promoted recently, often with questionable claims of increasing immunity and reducing inflammation. Rosemary is used for cooking fish, chicken, meat, and pork, as well as used in stews, soups, sauces, preserves, dressings, and jams.

Certain aromas, including earthy, woody, infusion, and hay-like scents, rise when the plants are dried, while other scents, such as fresh, herbal, and pine-like scents, decrease. Around the world, traditional medicine makes extensive use of the fragrant plant rosemary due to its healing properties. Table 2 lists the different parts of rosemary and their traditional uses. In traditional medicine, rosemary's aerial parts are primarily taken orally for their anti-inflammatory, antispasmodic, headache-relieving, arthritic, choleretic, stomachic, gout-related, analgesic, wound-healing (poultice), diuretic, antidepressant, and antirheumatic properties. Bajalan et al. [20] reported the use of a rosemary leaf extract for its antioxidant properties.

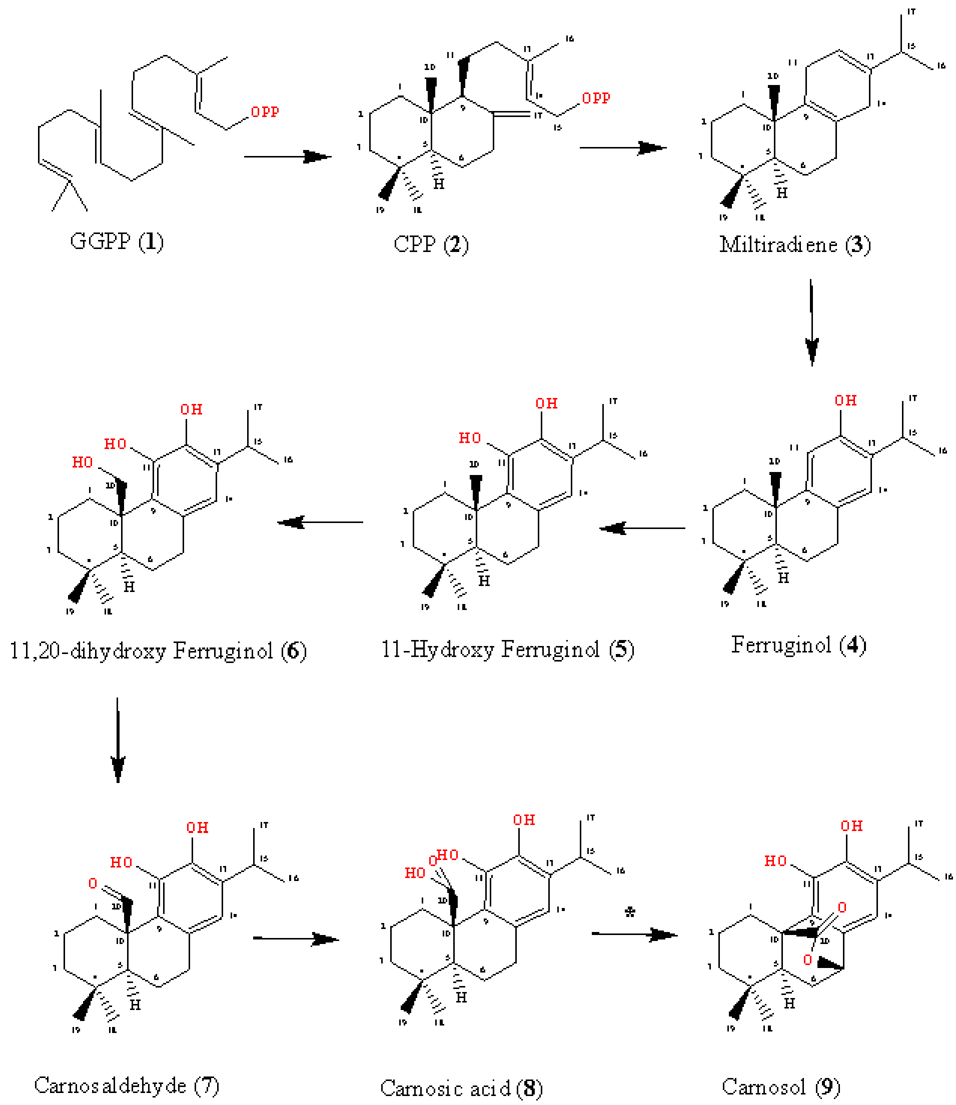
Its secondary metabolites are attributed to different biological activities such as antioxidant [21-23], antibacterial [10,22,24-26], antimutagenic [22,27-29], anti-inflammatory [30-31], antidiabetic [6,10,32], hepatoprotective [21,33], and anticancer properties [29,31,34-37].

Table 2. Summary of the current medicinal and cosmetic use of *R.officinalis*

No.	Cosmetic and culinary uses	Properties/ activities	Health benefits	References
1	Cosmetic and Culinary	Antioxidant property	Rosemary improves memory and is used as an antidepressant. It is also beneficial for the cure of cough and digestive disorders, for instance, spasms, diarrhoea, and flatulence.	[4-5, 23, 27, 32, 35-36]
2	Cosmetic	Anti-inflammatory activity	Carnosic acid inhibits the secretion of allergic inflammatory mediators and decreases atopic dermatitis; the extract of rosemary inhibits the production of nitric oxide (NO) within activated macrophages.	[23, 38, 39]
3	Cosmetic	Antipyretic activity	Rosemary reduces fever by increasing blood circulation	[40]
4	Cosmetic	Antibacterial activity	Rosemary essential oil (EO) is active against Gram (− and +) bacteria and exhibits intense inhibitory activity against highly resistant bacterial strains.	[36]
5	Cosmetic	Antifungal activity	Rosemary oil can inhibit the growth of *C. albicans*; the extract of rosemary was responsible for inhibiting the growth of fungi.	[32]
6	Cosmetic	Alopecia	Extracts of rosemary enhance the growth of hair	[41]
7	Culinary	Antilipidemic effects	Rosemary reduces total cholesterol, fasting plasma glucose, LDL-C (low-density lipoprotein cholesterol), and triglycerides, and enhances HDL-C. (high-density lipoprotein cholesterol)	[27]
8	Culinary	Analgesic activities	Rosemary essential oils have been consumed to relieve dysmenorrhea, renal colic pain, respiratory disorders, because of their antispasmodic features	[5, 42]
9	Culinary	Food additives activities	Rosemary essential oil (EO) helps to delay the onset of rancidity, besides preserving colour, flavour, and nutrients.	[5]
10	Cosmetic	Aromatherapy	Rosemary essential oils decrease nervous tension and stress levels, enhance mental activity, provide reassurance, clarity, and release fatigue, in addition to supporting respiratory function.	[4]

5.1 Antioxidant properties

In a variety of biological models, the antioxidant potential of rosemary extracts has been developed for widespread commercial use in the field of food safety [21-22,27,43]. The subsequent cleavage of hydrogen from the hydroxyl groups at C-20 produces carnosaldehyde (7) and carnosic acid (8). The literature revealed that the biosynthesis of carnosol (9) is a spontaneous process [28] (Figure 2). One study has reported the immediate conversion of carnosic acid (8) to carnosol (9) in leaves [44]. Studies conducted over the past few decades have demonstrated that compounds with a catechol functional group have a free radical scavenging effect, as they contain natural polyphenolic metabolites that help to lower oxidative stress in cells [27-28,43].



* spontaneous

Figure 2. Proposed biosynthetic pathway of tricyclic diterpenoid carnosic acid and carnosol

5.2 Anti-tumor activity

R. officinalis's anti-cancer mechanism has been shown to have an anti-proliferative effect on various human cancer cell types. Rosemarinic acid (10), carnosic acid (8), and carnosol (9) stimulated the apoptotic pathways in various cancer cell lines through the production of nitric oxide [28,35]. Carnosic acid is the primary apoptosis regulator [28,35]. Additionally, rosemary extract has strong anti-tumor properties. By reducing the adhesion of epidermal DNA and carcinogens, a study has shown that the extract reduces skin cancer in mice [45]. According to Hanahan and Weinberg [46], the primary characteristics of cancer cells are their tendency to metastasise and decreased capacity for apoptosis. By preventing carcinogens from attaching to the DNA of the epidermis and thus preventing skin carcinogenesis in mice, rosemary extract can demonstrate antitumorigenic effect [45]. According to scientific research, compounds derived from rosemary can help prevent and treat cancer [47]. It was discovered that rosemary methanolic extract works well for carcinoma (A549) [48].

5.3 Antianxiety

According to Ferlemi et al. [49], adult male mice that were given rosemary tea orally had less anxiety. Humans who used sachets of lavender and rosemary essential oil showed the same effect, as indicated by lower scores on measures of test anxiety, personal remarks, and pulse rates [50].

5.4 Anti-inflammatory activity

In anti-inflammatory conditions such as spasmolytic, arthritic, and gout diseases, rosemary extracts containing carnosic acid (8), carnosol (9) [2-3,38-39], ursolic acid (12) [51], and flavonoids may be useful. The anti-inflammatory properties of rosemary may be determined by its volatile fragrance components, including camphor, borneol, and 1,8-cineole [2-3,40].

5.5 Anti-thrombotic effects

According to in vitro and in vivo inhibition of coagulation tests and inhibition of platelet reactivity, rosemary can prevent arterial thrombotic illness. An inhibitory effect on platelets is probably the basis for rosemary's antithrombotic action [52-53].

5.6 Anti-obesity activity

Even among children and adolescents, the prevalence of obesity is increasing rapidly on a global scale [46-47]. Obesity is known to be a significant risk factor for cardiovascular disease, type 2 diabetes, hypertension, dyslipidemia, and their sequelae [10,41,54]. As dietary functional components, rosemary and its active constituents have shown anti-obesity effects in numerous trials.

5.7 Anti-diabetic effect

The phenolic component carnosol (9) may be linked to the outstanding anti-diabetogenic action of rosemary extract [10,55].

6. Chemical compounds

The profile and percentage of each component in rosemary oil varies according to the location of cultivation and/or other factors such as phenology, fertilizer, and population of the source [56-57]. Pintore et al. [58] used gas chromatography retention index (GC–RI), GC mass spectroscopy (GC–MS), and carbon nuclear magnetic resonance (C-NMR) experiments to describe 58 components from rosemary oil from Sardinia and Corsica (Italy). Based on GC and GC–MS analyses, a research on Moroccan rosemary oil identified 91 chemical substances in total and proved the existence of three different rosemary chemotypes [59].

The composition of the dried rosemary leaves is shown in the paragraph that accompanies. 1,8-cineol (15–20%), camphor (15–25%), borneol (16–25%), bornyl acetate (up to 7%), and α-pinene (25%) are the main constituents of rosemary oil. The oil also contains trace amounts of β-pinene, linalool, camphene, sabinene, myrcene, α-phellandrene, α-terpinene, limonene, p-cymene, terpinolene, thujene, copalene, terpinen-4-ol, α-terpineol, caryophyllene, methyl chavicol, and thymol (Figures 3-5; Table 3). Camphor and bornyl acetate make up the majority of the subsequent distillation, whereas the first distillation fraction mostly contains α-thujene, α-pinene, camphene, β-pinene, and 1,8-cineole [60].

7. Commercial opportunities for farmers

The food enterprises have a greater demand for rosemary nowadays, so some farmers are interested in cultivating it. It can also be grown by farmers in semi-shade. Nevertheless, its cultivation is common in hilly regions. The CSIR-CIMAP, located in Lucknow, Uttar Pradesh, India, created the necessary distillation and agro-culturing technology. Although rosemary thrives in the climatic zones of Tamil Nadu, Karnataka, A.P., H.P., Assam, and Kerala, and is cultivated on large expanses of plantations where coconut, mango, rubber, and other crops grow, it is not possible to cultivate rosemary on a large scale in these states. Due to the ideal temperature and soil in Uttarakhand, especially in the Himalayan region, rosemary may be cultivated there.

The high demand for rosemary oil and the general interest in this crop present numerous opportunities for commercial rosemary cultivation. It is a perennial crop that grows for around three years and produces two to three leaf crops annually [28,35,61].

The crop is grown on a small scale in India, and the only way to satisfy the demand is through importation. The essential oil does not deteriorate over a long period of time when farmers and buyers store it regularly. Proper preservation improves the oil's quality and aroma. The Zhuming system is a shifting mechanism that growers may employ in mountainous terrain [28, 61].

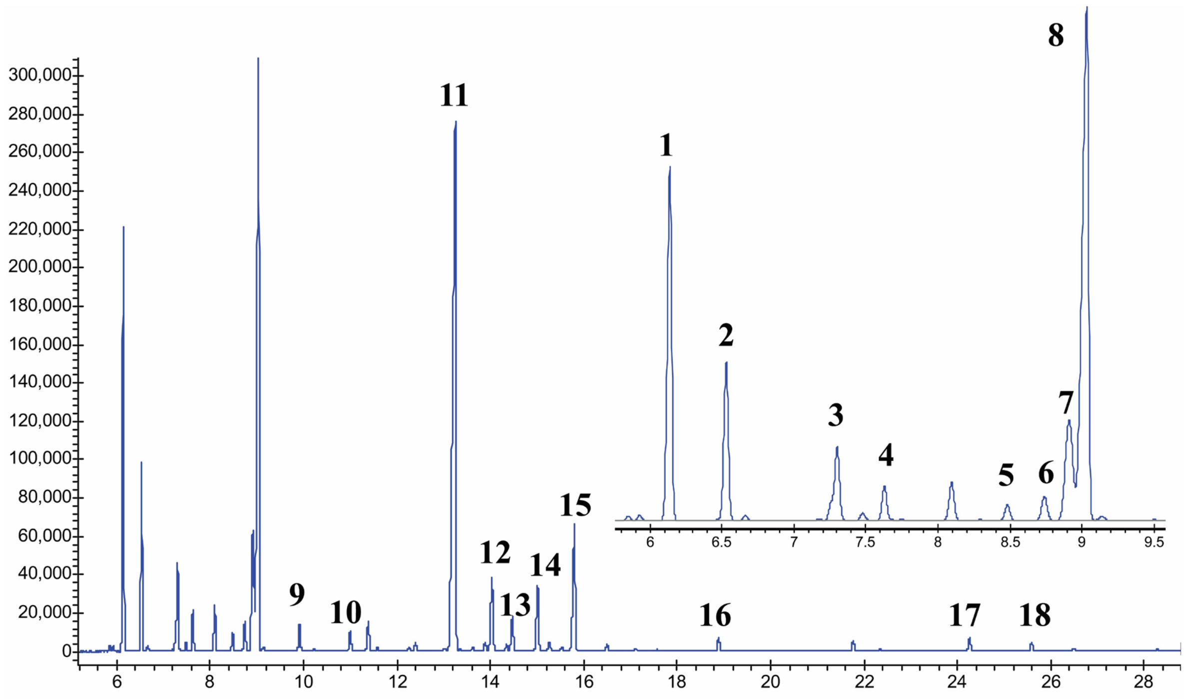
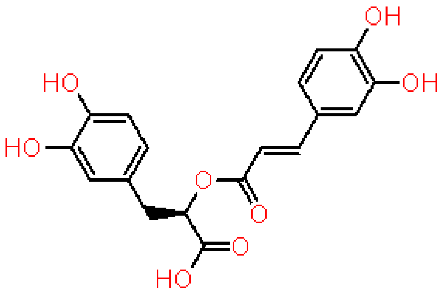
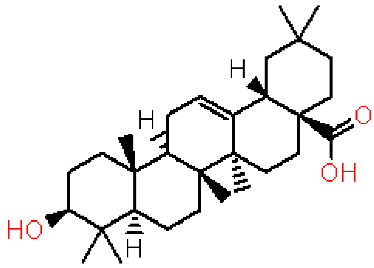


Figure 3. Representative gas chromatographic fingerprint of the rosemary essential oil

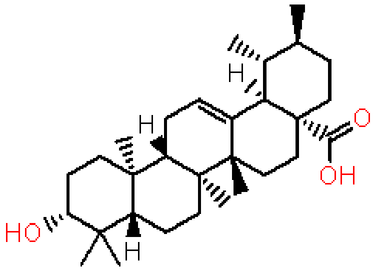
Figure 4. Essential oil of rosemary



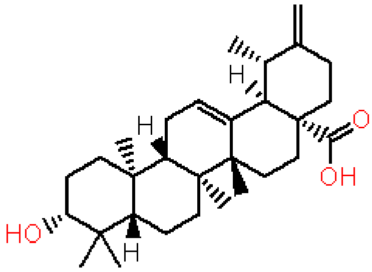
Rosmarinic acid (**10**)



Oleanolic acid (**11**)



Ursolic acid (**12**)



Micromeric acid (**13**)

Figure 5. Marker chemical components of rosemary plant extracts

8. Modern sustainable agricultural practices of Rosemary

The aromatic herb known for its culinary and therapeutic uses, rosemary, is more than just a plant; its cultivation is intricately linked to ecological concerns. The complex field of sustainable rosemary farming is explored, exposing the various facets of cultivation methods and their significant impacts on the nutritive and bioactive properties of this ancient herb. Sustainable rosemary farming goes beyond the traditional agricultural limits and embodies a comprehensive strategy that balances social responsibility, environmental management, and economic viability. The careful selection of growing techniques that maximize resource efficiency and reduce the impact on the environmental marks the beginning of the cultivation journey [28,61,62].

The prudent use of water resources is a key component of sustainable agriculture in the production of rosemary. As water scarcity is a global issue, sustainable practices place a strong emphasis on soil moisture management, rainwater collection, and precision irrigation methods to guarantee ideal development without placing an excessive amount of strain on water reserves [28,35]. Furthermore, by maintaining soil health and reducing the possible negative impacts on ecosystems, the adoption of organic agricultural methods—that avoid the use of synthetic fertilizers and pesticides—aligns with sustainability objectives [10,54]. The paragigm of sustainable agriculture, agroforestry, gains acceptance in the production of rosemary [8,35]. When rosemary is carefully planted among trees that complement it, biodiversity is increased, soil erosion is reduced, and a robust ecosystem is created for the herb to flourish [35-54].

9. Agroclimatic requirement

The fundamental concept of sustainability in cultivation techniques is embodied by this symbiotic interaction, which demonstrates the complex relationship between agriculture and nature [2,3,11-12]. Community-centric methods are also part of sustainable agriculture in rosemary farming (Figure 6). The social sustainability fabric is enhanced by involving local communities, honoring indigenous knowledge, and ensuring that fair labor practices are followed. Beyond the boundaries of field, sustainable rosemary farming becomes a catalyst for societal well-being by encouraging a sense of communal ownership and equal distribution of benefits [2-3,12,17].

9.1 Planting and spacing

The best vegetative method for growing rosemary is to cut off the stem. Healthy mother plants are used to make cuttings that are 10-15 cm long. After that, the cuttings are buried 6 to 10 cm deep in nursery beds of sandy soil that are partially shaded. Half to two-thirds of the length of the

Table 3. Marker components of *R. officinalis* from Uttarakhand, India, vis-à-vis the international standard (ISO)

Peak No.	RI	Constituents	Area % (in FID)	ISO 1342:2012#			
				Tunisian and Moroccan type		Spanish type	
				min	max	min	max
1	928	α-Pinene	10.4	9.0	14.0	18.0	26.0
2	943	Camphene	4.8	2.5	6.0	7.0	13.0
3	971	ß-Pinene	2.9	4.0	9.0	2.0	5.0
4	983	ß-Myrcene	1.1	1.0	2.0	2.5	4.5
5	1011	α-Terpinene	0.5	-	-	-	-
6	1018	p-cymene	0.9	0.5	2.5	1.0	2.0
7	1023	Limonene	5.1	1.5	4.0	2.5	5.5
8	1027	1,8-cineole	21.9	38.0	55.0	16.0	23.0
9	1052	γ-Terpinene	0.8	-	-	-	-
10	1082	Terpinolene	0.7	-	-	-	-
11	1093	Linalool	1.0	0.3	2.0	0.5	2.5
12	1141	Camphor	29.0	5.0	15.0	12.5	22.0
13	1160	Borneol	2.9	1.0	5.0	1.0	4.5
14	1171	Terpinen-4-ol	1.2	-	-	-	-
15	1185	α-Terpineol	2.5	1.0	2.5	1.0	4.0
16	1204	Verbenone	5.1	n.d.	0.4	0.7	2.5
17	1279	Bornyl acetate	0.5	0.1	1.6	0.5	2.5
18	1412	ß-Caryophyllene	0.5	-	-	-	-
19	1446	α-Humulene	0.3	-	-	-	-
	Total identified		92.1				

Essential oil of rosemary (*Rosmarinus officinalis* L.), ISO 1342:2012.

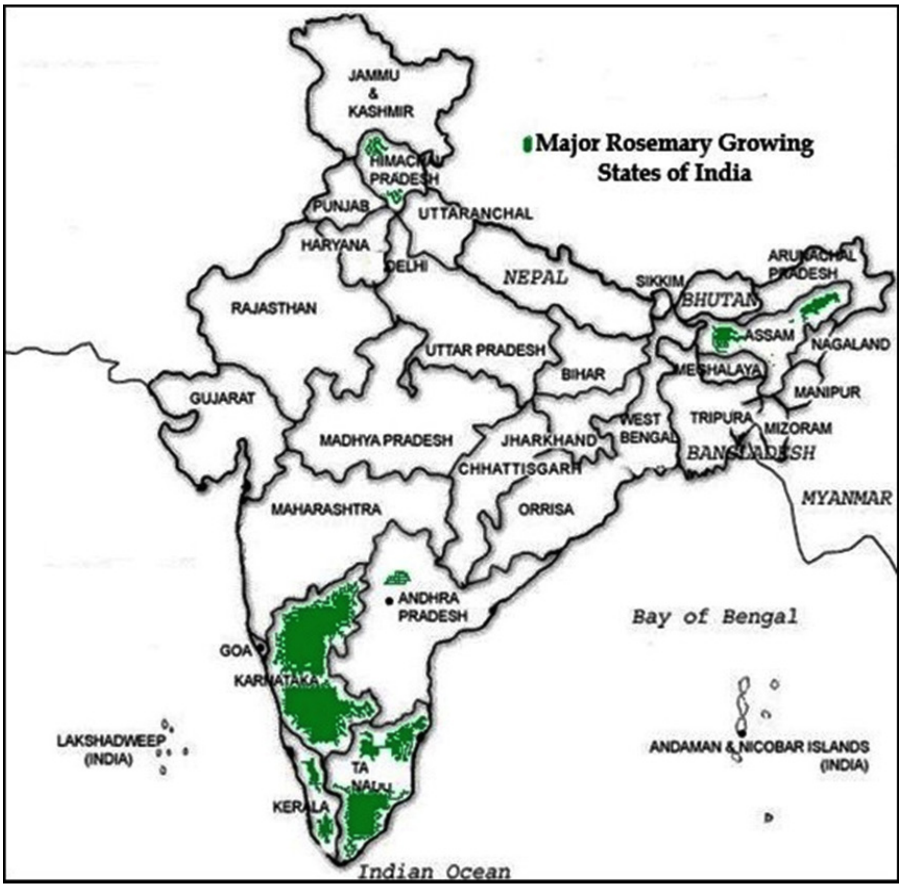


Figure 6. Major rosemary growing (green marked) states of India

cutting is placed in the appropriate growing medium. In four to five weeks, rooting hormones will help the roots grow. The best effect will come from a mist bed with a heated floor. They can also be grown in seed pots or small polybags. This facilitates the easy transfer of rooted cuttings. The seeds take a very long time to sprout. Cross-pollination is a constant issue. Therefore, it is not a good idea to cultivate true-to-type plants from seed unless it is adequately managed. In the main field, rooted cuttings or seedlings that are eight to ten weeks old are planted at a 45 cm × 120 cm spacing. Approximately 20,000 plants per hectare generate the most essential oil. According to the CSIR-CIMAP, Lucknow, the highest yield is obtained when the plants are planted at a spacing of 45 cm by 45 cm [7-8].

9.2 Nutrition approaches

Plenty of fertilizer is not needed for rosemary crops. The herbage and oil output of rosemary are strongly influenced by the stage of harvest and fertilizer levels. Rosemary was ploughed well before relocating the young plants and applied with 15 to 20 tons of well-rotted manure per hectare. When N (nitrogen) fertilizer is applied, the crop often reacts to it. An increasingly significant component of environmentally sound agriculture is the integrated provision of nutrients to plants through deliberate mixtures of sources [7,8,60,61]. However, the quality of the essential oil may be impacted by the overuse of inorganic fertilizers. The soil is treated with a basal application of NPK 80:40:40 kg, as suggested by the CSIR-CIMAP. To encourage vegetative development, nitrogen is administered as a side dressing in divided dosages. The CSIR-CIMAP, Lucknow, has suggested that the best crop yields can be achieved with a plant spacing of 45 cm × 45 cm and a nitrogen application of 300 kg/ha/year.

9.3 Irrigation

Until the plants are firmly established, irrigation is crucial during the transplanting process. Until the plants are established, the crop is initially irrigated twice a week. After that, watering once a week is sufficient. This crop can tolerate longer periods of drought as it is naturally drought-resistant. Since the plant cannot withstand a situation of water logging, care should be taken to ensure that it is not over-irrigated [7-8].

9.4 Intercultural operations

Weeds have an impact on oil yield and quality, hence weeding and hoeing by hand are crucial. Weeding should be done approximately one month following each harvest. Because rosemary roots are extremely susceptible to harm, it is important to take care not to damage them when hoeing. This may cause the branches or the entire plant to dry up, which can drastically lower the yield if there are many dried plants [7-8].

9.5 Crop protection

Farmers should refrain from overwatering their plants because it can lead to fungal problems. Researchers have discovered that damp soils are the breeding ground for diseases, including powdery mildew and root rot. Rosemary is susceptible to thrips, mealybugs, spider mites, and whiteflies. Applying insecticidal soap with light horticultural oil, together with careful crop rotation and monitoring, will help keep pests away from the leaves [7-8].

9.6 Harvest method and yield

Make use of a well-sharpened cutting tool to harvest rosemary, being extremely careful not to damage the roots. Leave the growing point (nodes) below the cutting point for harvesting rosemary branches, which should be around 15 cm above the ground. The weather, geographical location, and soil fertility can all affect the harvest time for rosemary. Only two harvests are produced in the first year, with the crop being ready for harvest eight months after planting. In subsequent years, three to four harvests can be produced at intervals of 100–120 days. The plants begin to bloom early in warmer, lower-altitude regions and later at higher altitude, depending on the plantation's exposure. Fresh rosemary leaves yield 1% oil in the laboratory's hydro-distillation process, while shade-dried leaves yield 3%. Nonetheless, a yield of 0.7% is deemed adequate in field distillation equipment. About 85 to 100 kg of oil per hectare per year can be produced from 12 to 15 tonnes/ha of herbage each year [7-8].

9.7 Storage of oil and agro-economics

Steam-based distillation is used to isolate the volatile oils, from plants that produce essential oils. In order to preserve its green color and prevent flavor loss due to essential oil volatilization, rosemary should be dried at temperatures lower than 40 °C. Fresh vegetables should be free of extraneous objects, look crisp and fresh, and have a nice color and flavor. It is recommended to store the extracted essential oil in a small, colored glass bottle in a cold, dry place, such as in the refrigerator if possible, and always to replace the container's top after use [3,7-8].

10.Tissue culture

Designing the procedures for rosemary in vitro regeneration necessitates a continuous propagation (Table 4) [63-67]. Recent research on the herb's literature and a SWOT (Strengths, Weaknesses, Opportunities, and

Threats) analysis has increased knowledge on the use of leaves as explants, which are known to produce volatile bioactive compounds [68, 69]. Leelavathi et al. [70] found a standard method for accelerating clonal multiplication employing in vitro axillary buds of rosemary on MS media, supplemented with 6-benzylaminopurine (8.88 M) + IAA (2.85 M) for the induction of numerous shoots to a large number.

Table 4. Explants, best recommended treatment, and responses in *Rosmarinus officinalis* L.

No.	Explants	Best recommended treatment	Responses	References
1	Adventitious shoot	MS + 1 MG^{-1} 6-benzyl amino purine and 2 Mm proline	Elite clonal lines were developed	[68]
2	Apical buds	MSBM + 6-benzyl amino purine (8.88 µM) + IAA (2.85 µM)	80 % Survival frequency	[63]
3	Leaves	MS + 2.0 mgl^{-1} 6-benzyl amino purine + 1.5 mgl^{-1} NAA	Feat of the highest callus size, callus fresh and dry weight (g)	[69]
4	Young leaf	MS + 1.5 mgl^{-1} 6- benzyl amino purine + 1.5 mgl^{-1} NAAMS + 2.0 mgl^{-1} 6- benzyl amino purine + 1.5 mgl^{-1} NAA	Positive increase in the number of purine somatic embryos after 45 days	[69]
5	Shoot tips	MS + 6-benzyl amino purine 1.0 + NAA 0.125	Highest callus induction and growth	[64]
6	Leaves	MS medium + 1mg/1 CPPUWPM + 1 MG/ 1 CPPU	The highest mean number of shoots per explant was 2.40 shoots/explants produced	[66]
7	Seeds	MS + modified growth regulators the level of 5.0 mg/l Kinetin medium modified to 3 mg/l BA + coconut milk at 5 ml/l.At the level of 3.0 mg/l BA.When coconut water at 5.0 ml/l + Kinetin 3.0 mg/l	Highest number of shoots/explants	[65]
8	Shoot tips	MS + 6-benzyl amino purine + NAA (MS I) 1 mg l^{-1}/0.1 mg l^{-1} and (MS II) 2 mg l^{-1}/0.1 mg l^{-1}	The density of trichomes was found to increase threefold in comparison with in vivo	[67]

11.Trade, marketing and export

The demand for rosemary leaves, both fresh and dry, is increasing globally both in terms of price and supply [71-74]. Additionally, there is a growing trend of demand for rosemary essential oil worldwide [3,8,60,75]. The market for rosemary extracts was valued at USD 215 million in 2019 and is projected to grow at a 3.7 percent annual rate between 2020 and 2030 due to the strong demand for rosemary as a food additive and ingredient in food and beverages.

India exported 3,932 shipments of rosemary between November 2023 and October 2024 (TTM), according to India export data from Volza. These exports made by 509 Indian exporters to 1,274 buyers, represented a 17% increase over the previous 12 months. During this time, 314 cargoes of rosemary were exported from India in October 2024 alone. This is a sequential growth of 0% from September 2024 and an 8% year-over-year growth from October 2023. India's top export destinations for rosemary are the US, Australia, and Germany. South Africa, Turkey, and India are the top three exporters of rosemary worldwide. With 35,226 shipments, India is the world's largest exporter of rosemary, followed by Turkey (7,580 shipments) and South Africa (5,077 shipments) [3,7-8,74].

A comprehensive data or graphic that shows the production of rosemary (*Rosmarinus officinalis* L.) in India throughout time is not readily available in general. Nonetheless, data indicates that rosemary is being increasingly grown in some parts of India, especially for the production of essential oils (Figure 6). According to studies, the yield and composition of essential oils are influenced by factors/variables such as harvest times, soil conditions, and climate.

Conclusion

According to the European Pharmacopeia, *R. officinalis* is an ancient plant with therapeutic properties. Over the years, it has been widely utilized to treat a variety of diseases. In the past decades, in vitro, in vivo, and human research have been conducted to scientifically substaintiate the plant's claimed medicinal properties. Further research is required to investigate the pharmacological activities of the active phytochemical ingredients. The volatile oil is reported to include at least 140 different chemicals, such as carnosic acid, ursolic acid, rosmarinic acid, oleanolic acid, flavonoids, and phenolic acids. These substances serve as building blocks for plant derivatives that are extremely antioxidant. In moderation, rosemary is also used as a skin conditioner and fragrance in cosmetic products. Rosemary has a lot of promise for topical application and keeps cosmetics from deteriorating. It is an antibacterial and bactericidal agent that absorbs UV light. Additionally, its anti-alopecia properties are being studied. As of right now, it is known that this plant's benefits are associated with the way its molecules work interact with other plant extracts. Its primary bioactive ingredients and their modes of action can be clarified by further investigation. Nowadays, this plant is used as a cosmaceutical product to keep the skin in a state of homeostasis and prevent the appearance of several skin disorders.

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Authors' contributions

AK was responsible for experimentation, NS conducted data curation. Manuscript preparation: MNS-data recording, distillation; MS-experimentation; CS-Chemical fingerprinting; manuscript editing, and RKL was involved in planning, experimentation, and statistical analyses of this study.

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this article.

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